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A novel weld transition joint by friction surfacing

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Abstract

A novel weld transition joint by solid state friction surfacing method is developed. Weld transition joint between Cr-Mo steel and austenitic stainless steel was developed by depositing series of Ni-alloy coatings between them. These multi-layered coatings with gradual rather than abrupt change in coefficient of thermal expansion between Cr-Mo and austenitic stainless steels are expected to improve the service life of dissimilar metal welds used in thermal and nuclear industries. Metallurgically bonded coatings with minimal dilution were achieved. Grain refinement and increase in hardness were observed in all the coatings due to the dynamic recrystallization.

Keywords: Weld transition joint; Friction surfacing; Dissimilar metal welds; Dynamic recrystallization

Fusion welded dissimilar metal weld (DMW) joints comprising Cr-Mo steel (T/P91) and austenitic steel (AISI316, 304H) used for thermal and nuclear power generation plant applications often exhibit shorter creep lives than designed life period [1]. One of the main reasons attributed to these failures is the difference in the coefficient of thermal expansion (CTE) between ferritic T91 (13.18×10^{-6}/K) and austenitic stainless steels (18.0×10^{-6}/K). Because T91 has a lower CTE, it will try to constrain the stainless steel weld from expanding [2] resulting in highly localized stresses at the interface leading to failure. Other failure reasons include carbon-denuded zone [3] and residual tensile stresses [4]. Though filler metals with an intermediate CTE (Inconel 82 and Inconel 182) are used to improve the life of DMWs, failures still occurred in these DMWs [5]. It would be ideal if a weld transition joint could be developed with gradual rather than abrupt change in CTE by depositing functional graded multi metal layers. Developing such multi-layer deposition by fusion welding is not possible in view of its limitations such as high amounts of dilution between dissimilar metals, physical defects such as porosity, cracking and metallurgical damage such as formation of martensite. Developing series of multi-metal layers between two dissimilar metals is relatively convenient with solid state welding techniques. To our knowledge, no such attempt has been made so far. In this work, it is proposed to develop a weld transition joint between T91 and AISI 316 by depositing a number of Ni-based alloy interlayers between them by using solid state friction surfacing process. These proposed interlayers are as follows: Inconel 625 (CTE: 14.40×10^{-6}/K); Inconel 718 (14.85×10^{-6}/K); Inconel 600 (15.30×10^{-6}/K); Inconel 800H (16.02×10^{-6}/K). In view of the gradual change in CTE of series of Ni-based interlayers that are deposited between T91 and AISI 316, the DMW weld failure could be controlled. Friction surfacing process is applied for depositing surface coatings [6–8] including – Ni-based alloys [9,10]. In this work, a feasibility study is taken up to develop a transition joint between T91 and AISI 316 by depositing Ni-based alloy interlayers using friction surfacing. This study mainly focused on the microstructural evolution

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aspects. Further work is in progress in assessing their high temperature behavior such as stress rupture properties.

1. Materials and methods

Cr-Mo steel (T91) was taken in a plate form ($50 \times 50 \times 125$ mm) and was used as the substrate. Inconel 625, Inconel 718, Inconel 600, Inconel 800H and AISI 316 rods (12.5 mm diameter) were used to deposit coatings. Table 1 shows the chemical composition of materials used. A 2^3 factorial design of experiments was adopted in order to obtain defect-free layers and to arrive at suitable friction surfacing parameters. The parameters which resulted in interface bond integrity were selected which were as follows: rotational speed-1000 rpm, axial force-6000 N and dwell time 30 s. The sequence of friction surfaced coatings one over the other on T91 was as follows: Inconel 625, Inconel 718, Inconel 600, Inconel 800H, and AISI 316. The deposited coatings were machined to get a cylindrical rod and a transverse slice was cut by EDM in the length direction of the rod for bend test and microstructural evaluation. The intra and inter layer defects were assessed using optical microscopy and U-bend test. Microstructures of friction surfaced coatings were examined using optical and scanning electron microscopes. Grain size and Vickers microhardness (500 g load) were measured for coatings and compared with consumable rods. Energy dispersive spectroscopy (EDS) was used to determine the chemical composition of friction surfaced coatings near the interface to assess dilution of the coatings.

2. Results and discussion

The interfaces of the friction surfaced coatings and the substrate are shown in Fig. 1. Complete bonding without any voids and cracks at the coating interfaces was noticed. Oxide scales formed on the rubbed side of the rod did not affect the bonding between coating layers [11]. The U-bend test showed no de-bonding between the successive coating layers. EDS spot analysis (Table 2) (corresponding to points shown in Fig. 1) showed minimal dilution near the coating interfaces.

Friction surfaced coatings showed equiaxed fine grained microstructures in contrast to their consumable rod counterparts (Fig. 2). The grain sizes (in μm) of different coatings were found to be as follows: Inconel 625 (rod 11.8 ± 4.9; coating 3.6 ± 0.8); Inconel 718 (67.4 ± 4.4; 18.8 ± 1.2); Inconel 600 (62.8 ± 8.4; 12.4 ± 2.2); Inconel 800H (84.4 ± 10.2; 12.8 ± 4.0) and AISI 316 (48.3 ± 7.8; 14.6 ± 1.4). Significant reduction in the grain size of friction surfaced coatings compared with their consumable rod counterparts is an indication that the friction surfaced coatings are subjected to dynamic recrystallization. This is in line with earlier studies [7,12–15]. High strain rates and temperatures involved in the friction based process result in the dynamic recrystallization and grain refinement. Relatively high strain rates (>400 S^{-1}) and temperatures ($0.8–0.9T_m$) are reported for the friction surfaced coatings [7,8,12]. These severe plastic deformation conditions promote nucleation and growth of a new set of grains at prior deformed grain boundaries which eventually produce grain refinement. The specific nature of the friction surfacing and friction stir welding/processing enables the simultaneous occurrence of the continuous and discontinuous recrystallizations [16–18]. The grain refinement during friction stir welding/processing is driven by geometric effects of strain, grain subdivision and thermally activated high-angle grain-boundary migration leading to the formation of a refined, low-aspect-ratio grain structure [19–21]. Different hot restoration mechanisms such as dynamic recovery and dynamic recrystallization are responsible for the grain refinement in friction surfaced coating materials. Stacking fault energy of the processed material plays a vital role in deciding the type of hot restoration mechanism. Dynamic recovery processes are slow in a low or medium stacking fault energy materials such as copper, nickel, and austenitic iron. Dynamic recrystallization may take place in these materials when a critical deformation condition is reached [22]. In the present work nickel base alloys are friction surfaced to develop a transition joint between T91 and AISI 316. Nickel base alloys have medium stacking fault energy (≈128 mJ m^{-2}), therefore, dynamic recrystallization is believed as a hot restoration mechanism in the present case.

Grain size of friction surfaced coatings was found to change from top to bottom and is in line with earlier works [12]. The large size grains are observed near the top surface of the coating compared with its bottom surface. A difference of about 40% in the grain size was observed from top surface to bottom surface of different Ni-based alloy coatings and AISI 316 friction surfaced coatings. The difference in the grain size across the cross-section of coatings can be attributed to the difference in cooling rates experienced by the friction surfaced coatings. Further, it is observed that fresh depositions during multiple layer build-ups did not cause noticeable coarsening of grains in the previously deposited layers indicating that temperatures and cooling rates involved in friction surfacing will not lead to significant microstructural changes in the substrate.

It is further observed that friction surfaced coatings of Ni-based alloy alloys showed decrease in density of twin boundaries than the consumable rod counterparts (Fig. 2). The decrease in the density of twin boundaries

Table 1
Chemical composition of substrate and consumable rods.

Materials	Elements (in wt.%)						
	C	Cr	Mo	Nb	Ti	Ni	Fe
T91 (substrate)	0.10	9.23	1.14	–	–	0.3	Balance
Inconel 625	0.03	22.9	8.7	3.6	0.2	Balance	3.9
Inconel 718	0.04	18.8	3.3	5.1	1.1	Balance	17.2
Inconel 600	0.05	16.1	–	0.03	0.3	Balance	9.0
Inconel 800H	0.07	20.4	–	–	0.51	Balance	48.4
AISI 316	0.08	18.3	2.02	–	–	10.2	Balance